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FULL SCALE FIRE TESTS OF A NEW LIGHT GAUGE STEEL FLOOR-CEILING SYSTEM

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ABSTRACT

Cold-formed steel members can be assembled in various combinations to provide cost-efficient and safe light gauge floor systems for buildings. Such Light gauge Steel Framing (LSF) systems are widely accepted in industrial and commercial building construction. An example application is in floor-ceiling systems. Light gauge steel floor-ceiling systems must be designed to serve as fire compartment boundaries and provide adequate fire resistance. Fire-rated floor-ceiling assemblies formed with new materials and construction methodologies have been increasingly used in buildings. However, limited research has been undertaken in the past and hence a thorough understanding of their fire resistance behaviour is not available. Recently a new composite floor-ceiling system has been developed to provide higher fire rating under standard fire conditions. But its increased fire rating could not be determined using the currently available design methods. Therefore a research project was carried out to investigate its structural and fire resistance behaviour under standard fire conditions. In this research project full scale experimental tests of the new LSF floor system based on a composite ceiling unit were undertaken using a gas furnace at the Queensland University of Technology. Both the conventional and the new steel floor-ceiling systems were tested under structural and fire loads. Full scale fire tests provided a good understanding of the fire behaviour of the LSF floor-ceiling systems and confirmed the superior performance of the new composite system. This paper presents the details of this research into the structural and fire behaviour of light gauge steel floor systems protected by the new composite panel, and the results.

1. INTRODUCTION

Light Gauge Steel Framing (LSF) floor systems made of cold-formed steel lipped channel sections are commonly used in the building industry [1] [2]. However, these thin cold-formed steel sections heat up quickly under fire conditions, resulting in rapid reduction to their strength and stiffness. Plasterboards provide protection to steel joists during building fires by delaying the temperature rise in the cavity. The fire resistance of a floor is its ability to remain stable under exposure to fire. It is usually expressed in terms of its fire resistance rating, which is the length of time the floor can stay exposed to fire in a standard fire resistance test without losing its load-bearing or fire separating functions. Fire rating of LSF floor systems is provided simply by adding more plasterboard sheets to the steel joists (the traditional method). Innovative fire protection systems are therefore essential without simply adding on more plasterboard sheets, which is inefficient. Hence a new composite LSF wall system has been proposed recently at the Queensland University of Technology (QUT) to provide higher fire rating under fire conditions [3]. A new composite panel system was developed in which insulation was used externally between plasterboards instead of the conventional cavity insulation located within the stud space (see Table 1). The use of this composite panel system was investigated in [3], but was limited to LSF wall systems.

This research investigated the structural and fire performance of LSF floor systems with the new composite ceiling unit under standard fire conditions. It improved the understanding of the effects of relevant parameters by comparing the results with the structural and fire performance of conventional floor systems. Full scale tests of the new LSF floor systems based on the composite panel system for the ceiling unit were conducted. This paper presents the details of the experimental study into the thermal and structural performance of three LSF floor assemblies chosen. Details of the results including the temperatures and deflections measured during the tests are presented along with the joist failure modes. The local and global joist failure modes observed during the tests are also discussed.

2. TEST SPECIMENS

Full-scale fire tests were conducted to investigate the structural and thermal performance of LSF floor systems under fire conditions. The LSF floor system components in Australia are commonly made of 1.15mm G500 lipped channel section joists (180x40x15) at 600 mm spacing, two layers of 16mm plasterboards and plywood chosen without resilience channels and unlipped channel tracks. In this experimental study, both the conventional floor systems (with and without cavity insulation) and the new composite floor-ceiling systems were tested under structural and fire loads. The insulation used was rock fibre. In the new composite floor system, insulation was sandwiched between the plasterboards on the ceiling side of the steel frame instead of being placed in the cavity (see Specimen No.3 in Table 1). The LSF floor specimens were first loaded to pre-determined values, and then exposed to standard fire conditions on the ceiling side (Plasterboards). Table 1 gives the details of the three full scale floor specimens used in this study. Test specimens were built using four joists, two tracks, two layers of plasterboard and one layer of plywood. The floor area was more than 5 m^2 (2.4m x 2.1m) with a span of 2400 mm and the floor specimen was simply supported along its two short sides.

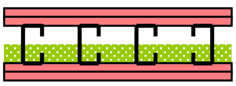
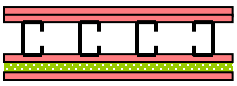
Test	Configuration	Insulation
1		None
2		Rock fibre (Cavity insulation)
3		Rock fibre (External Insulation)

Table1: Details of test specimen configurations

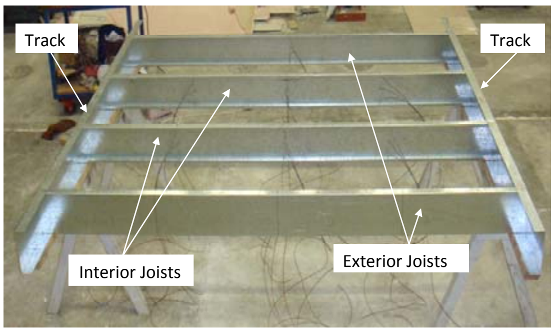
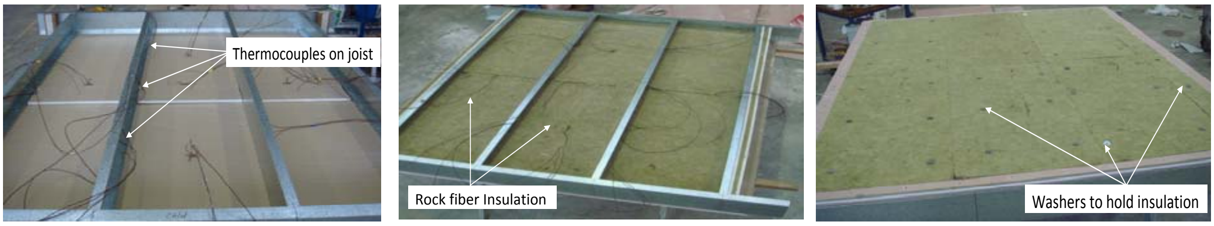


Figure 1: LSF floor frame

All the joists and tracks used were fabricated from galvanized steel sheets having a nominal base metal thickness of 1.15 mm and a minimum specified yield strength of 500MPa (G500 steel). The frames consisted of four horizontal joists made of 180 x 40 x 15 x 1.15mm lipped channel sections as shown in Fig.1. Test frames were made by attaching the joists to the top and bottom tracks made of 182 x 50 x 1.15 mm unlipped (plain) channel sections using 12 mm long self-drilling wafer head screws. Test steel frames were lined on the ceiling side (fire side) by two layers of gypsum plasterboards (16mm) manufactured by Boral Plasterboard under the product name Fire-stop to suit the requirements of relevant Australian Standards [4]. The face layer of fire side plasterboard was fixed in the same manner as the first layer, but its joints were staggered by 200mm.



(a) Without insulation (b) With cavity insulation (c) With external insulation

Figure 2: Test specimens 1, 2 and 3

K type thermocouple wires were installed to measure the temperature variations across the width and along the length of test floor as shown in Fig.2 (a) (plasterboard and joist surfaces). On the joists, the thermocouple wires were attached to the hot flange, web and cold flange. The wires were drawn to the ambient side through tiny holes drilled in the unexposed plywood boards/plasterboards. During the first test, there was considerable smoke, which was followed by plywood burning although plywood was on the ambient side. Hence plywood was not used in Test Specimens 2 and 3. Instead two plasterboards without any external insulation were used. Three 25 mm thick Rock fibre insulation layers were used in the cavity space between the joists after fixing the two plasterboards on the fire side along with their associated thermocouples in Test Specimen 2 (Fig.2 (b)). Fig.2 (c) shows the installation of rock fibre cavity insulation. The construction of Test Specimen 3 required the insulation to be laid not within the cavity as in Test Specimen 2 but outside the cavity and between the base and face layer plasterboards on the ceiling side (fire side) (Fig.2(c)).

3. TEST SET-UP

A propane fired gas furnace was used in this research to undertake the full scale fire tests. The furnace temperature was measured using four type K mineral insulated and metal sheathed thermocouples symmetrically placed about the horizontal and vertical centre lines. The average temperature rise of these thermocouples served as the input to the computer controlling the furnace according to the standard cellulosic temperature-time fire curve given in AS 1530.4 [5]. A heavy steel frame was specially constructed to support the test floor specimens. It consisted of two columns firmly bolted to the strong floor and a universal beam connecting the two columns to form an ‘H’ shaped portal frame (see Fig.3). The gas furnace only allowed test floor specimens to be set in a vertical position. Hence the transverse loads on the floor specimens were applied in a horizontal direction.

In order to simulate a uniformly distributed loading present in LSF floor systems, a load distribution system was developed (see Fig.4) Each load distribution unit consisted of a main spreader beam and two secondary spreader beams. At the ends of each secondary beam there were 180 mm x 180 mm loading plates to apply the loads to each joist. Using a horizontal loading distribution unit was more complex and in order to overcome associated problems, a load transfer system was developed to transfer the horizontal reaction loads of the load distribution system to the strong floor. The target load of 18 kN per jack (4.5 kN per loading point) was applied gradually at a constant rate by the two hydraulic jacks. This target load was determined based on a load ratio of 0.4 where the load ratio is the target load in the fire test to the ultimate failure load of the floor specimen at ambient temperature. The latter ultimate failure load was predicted to be 22 kN per joist using the design rules in AS/NZS 4600 [6, 7].

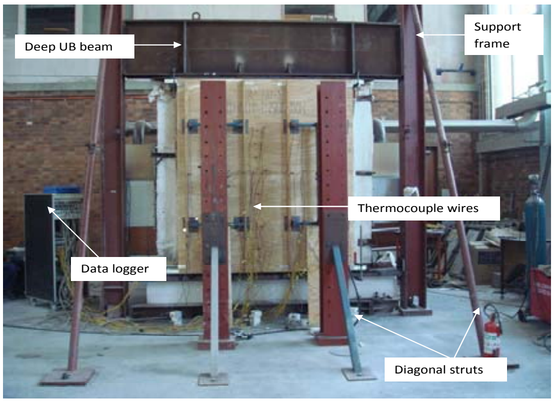


Figure 3: Test set-up

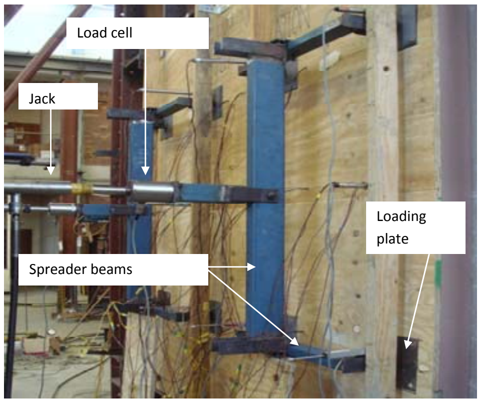


Figure 4: Load distribution unit

To measure the out of plane deflections of floor specimens, 12 Linear Variable Displacement Transducers (LVDT) were used at 0.25L, 0.50L and 0.75L heights along the length of each joist. During the fire test the lateral displacements of the floor, the temperature readings from all the thermocouples and the furnace pressure readings were taken using an automatic data-acquisition system at intervals of one minute.

4. OBSEVATIONS AND RESULTS

4.1. Visual Observations

In all the tests, at the end of 4 minutes of starting the furnace, smoke was seen coming out from the top of the floor specimen due to the burning of the plasterboard paper on the exposed surface. After about 10 minutes thick smoke and steam were seen to escape from the outer edges from the top of the floor. The presence of steam in the mixture of gases escaping was evident as heavy condensation of steam into water was clearly seen on the bottom flange and web of the top beam in the support frame and the top track of the specimens. There were also periods of more smoke from the specimens for almost 30 to 40 minutes. This would probably indicate the burning of inside plasterboard paper.

From the beginning of the fire test, the floor specimens were observed to be bending towards the furnace. This continued until the failure and resulted in failing towards the furnace. Top part of the test specimen had a higher lateral deflection than that of the lower part of the specimen. The lateral deflection was the largest in Test Specimen 2 with cavity insulation compared with Test Specimens 1 and 3 (external insulation and no insulation). This was due to higher temperature difference between hot and cold sides of the joists which caused noticeable higher thermal bowing in this test compared with other two tests. Maintaining the load on the floor specimen was difficult at failure stage with the hand pump controlling the jacks being operated more frequently and rapidly. The failure was sudden in all the specimens with the load dropping quickly with joist buckling in the inward direction and the plywood /plasterboards on the ambient side. The ambient surface of floor specimen recorded temperature values well below the insulation failure temperature (140°C) during all three tests. The failure of the specimen was due to the structural failure of the joists.

4.2. Behaviour of the Specimens

It was noted that torsional buckling flexural buckling about the minor axis of joist were fully prevented by the lateral support offered by the dual layers of plasterboard throughout the test. The central joists in all the specimens experienced local failures at the support as shown in Fig.5. Local web buckling waves were observed along the length of joists in Test Specimens 1 and 2. (See Fig.5).

Specimen	Insulation	Failure Mode	Failure Time (min)
1	None	Structural	107
2	Rock fibre Cavity insulation	Structural	99
3	Rock fibre External insulation	Structural	139

Table 2: Failure time of test specimens

Figure 5: Failure modes of joist

4.3. Results

The results of full scale fire tests are summarized in Table 2. It gives the fire resistance ratings (in minutes) of the three LSF floor specimens tested under a constant load during the fire tests. This experimental study provided the fire performance results for the LSF floor systems using both conventional (with and without cavity insulation) and external insulation. The results confirmed the superior performance of LSF floor system using external insulation over cavity insulation. Detailed results of time-temperature profiles and structural behavioural characteristics of joists in LSF floor systems obtained from this study can now be used in their numerical analyses. Following section present some of the main findings.

5. DISCUSSION

The temperature profiles of the externally insulated floor specimens were found to be the most favourable. This is probably because, any insulation by virtue of their physical presence essentially serves the main function of eliminating the transfer of heat across the floor cavity by radiation and convection which essentially are the faster modes of heat transfer as compared to conduction. No cavity insulation can reduce the transfer of heat towards the cold flange by conduction along the metallic cross-section of the joist. Thus the cold flange picks up heat from the hot flange by conduction along the web, which would be the fastest mode of heat transfer in the case of cavity insulated specimens. Because of the very low conductivity of the cavity insulating material as compared to steel, most of the heat gets directed and channelled along and across the steel joists which act as the heat sink. This raises their body temperatures much faster than in the case of non-cavity insulated specimens, thus making the very presence of cavity insulation a threat to the survival of steel during fire conditions. Externally insulated specimens on the other hand can offer a much higher level of protection to the joists as they are installed on the fire side of the joist, thus minimizing the transfer of heat by radiation (by virtue of their physical presence) and conduction (on account of their low conductivity). Rock fibre insulation when used externally was seen to give the maximum protection.

Average temperature profiles in joists (see Fig.6) show the thermal responses of joists and compare the performance of cavity insulated (with insulation and no insulation) test floor specimens with externally insulated specimens. In the case of cavity insulated specimen, the average temperature plateau (second phase) of joists was seen to last only up to 60 minutes in comparison to 90 minutes in the case of externally insulated specimen. The higher temperature differences across the joist cross-section in the cavity insulated specimen led to higher lateral deformations as compared to the externally insulated specimen. Fig.7 shows the lateral deflections for the cavity insulated and externally insulated specimens using rock fibre. After 80 minutes from the start of the test, the lateral deformations in the cavity insulated specimen was close to 13 mm, compared to about 6 mm in the case of externally insulated specimen. By the end of 90 minutes, the lateral deformation in the cavity insulated specimen had crossed 20 mm, whereas it was still less than 8 mm for the externally insulated specimens.

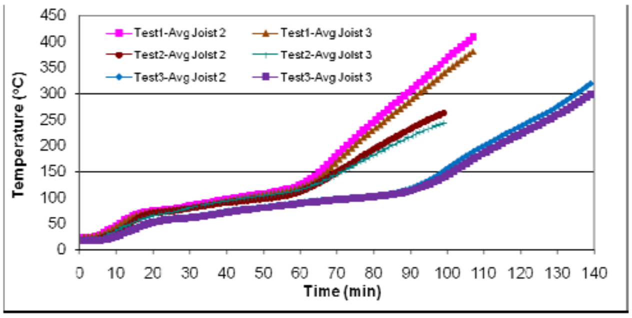


Figure 6: Average time-temperature profiles for the joist in Test Specimens 1, 2 and 3

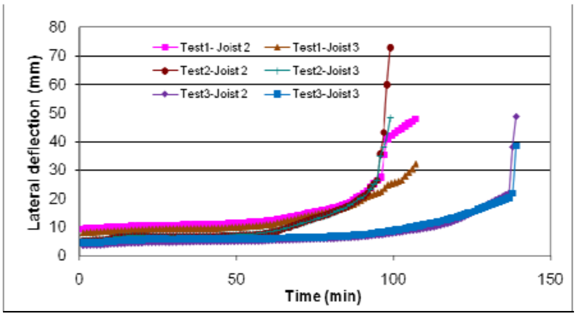


Figure 7: Lateral deflection - time profiles joists at upper level for the interior Test Specimens 1 , 2 and 3

6. CONCLUSION

This paper has presented the details of three full scale fire tests of a new LSF floor-ceiling system using external insulation and the results. Test results have shown the superior fire resistance characteristics of the new LSF system. Temperature measurements showed that structurally similar LSF floor panels will fail when their joists reach a critical maximum temperature and the fire resistance can be increased only by delaying the maximum temperature in the joists. This is confirmed by the increase in fire resistance time of Test Specimen 3, which was achieved by the delay in temperature rise in joists by the use of external insulation. This study has shown that the use of cavity insulation led to poor thermal and structural performance of LSF floors. In contrast, the thermal and structural performance of externally insulated LSF floor system was superior than traditional LSF floors with or without cavity insulation. Details of fire tests and the results are presented and discussed.

7. REFERENCES

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